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ABSTRACT

We find evidence for price clustering in both oil and coal price data. We further find that there is significant evidence that these clusterings represent psychological barriers, and that these affect both the level and the volatility of prices around these barriers.

JEL classification: G14; G15

Keywords: WTI oil futures, coal futures, gas, oil, psychological barriers, behavioural finance, clustering, barriers

PSYCHOLOGICAL BARRIERS IN ENERGY FUTURES

1. INTRODUCTION

If markets are efficient then we should, all things being equal and abstracting from trends and drift, note that prices evolve in a manner where the likelihood of any given change is approximatly equal. This would in turn then result in the distribution of "trailing" digits, the last digit of a price, being uniform and there being no systemic clusters of prices around digits, purported psychological barriers, or other numerical points. Price clustering as an invderives from the work of (Niederdorfer 1962) and (osborne 1965) and has since evolved to two distinct threads, clustering per se (which has been investigated in a number of markets) and the existence of purported psychological barriers (less usually investigated and the main thrust of this paper). That this is not the case is found in a number of markets, and this paper investigates further recent findings for such failure in two important energy markets. Using specifications applied in other asset markets we find evidence of such barriers in energy futures.

2. PSYCHOLOGICAL INFLUENCES IN ENERGY FUTURES PRICING

2.1. Psychological Influences on Energy Futures Traders

Both price clustering and psychological barriers research are concerned with how the market treats certain numbers, but are quite distinct areas of research despite partial overlap. There is a small but growing literature on psychological barriers and price clustering in stock markets (e.g. Ikenberry and Weston, 2008; Bhattacharya, Holden and Jacobsen, 2012). Price *clustering* is the phenomenon of pricing showing an excessive frequency of certain digits, and has been linked, in part, to a psychological preference for certain numbers such as round numbers (Mitchell, 2001). Psychological (price) *barriers* research is concerned with the idea of a perceived reluctance of prices to cross certain price points; something which the price clustering research does not address.

Research on such issues appears limited to date in the pricing of energy futures. This is partially perhaps down to a view that psychological factors should primarily affect the investment decisions of small investors who are most likely to be boundedly-rational in their decision making

(e.g. DeLong et al, 1990). Given that oil and coal futures are overwhelmingly traded by professional market participants (at least in volumn terms) there should be limited role for psychological influences in their trading behaviour according to this perspective.

This view has been challenged: Coval and Shumway (2005) show that Chicago Board of Trade (CBOT) traders display loss aversion,; O'Connell and Teo (2009) find evidence of currency trader overconfidence ; Coates and Herbert (2008) are able to link differences in testosterone levels (linked to risk taking) with differences in trading profitability amongst a group of professional traders. It should be mentioned that studies comparing professional traders with less experienced market participants consistently find that professional traders are less prone (but not immune) to behavioural biases compared to the less experienced groups (e.g. Venezia, Nashikkar and Shapira, 2011).

To date the research on these issues concerning energy futures pricing has examined price clustering. Two recent papers, Narayan, Narayan, and Popp (2011) and Bharati, Crain and Kaminski (2012) find price clustering in oil futures while Palao and Pardo (2012) find similar in carbon futures.

2.2. Psychological Barriers in Energy Futures

Psychological barriers have been detected in a number of markets primarily traded by professional traders, including foreign exchange (Westerhoff, 2003) and gold prices (Aggrawal and Lucey, 2007), suggesting a basis for investigating whether psychological barriers are present in energy futures pricing.

Following Aggrawal and Lucey (2007) the research in this paper investigates whether there are barriers in NYMEX oil and coal futures around digits which might be perceived as psychologically important price points. The tests run in this paper examine the presence of 10s and 1s psychological barriers. 10s psychological barriers test the two digits bracketing the decimal point, and 1s tests examine the two digits to the immediate right of the decimal point. Thus, if there are two prices of $34.55 and $39.67 then '45' and '96' will be extracted respectively as the 10s digits, and '55' and '67' will be respectively extracted as the 1s digits. An expectation based on prior studies is that barriers are most likely to exist at exact tens of dollars such as $30 or $40 so there should be lower frequency in the 10s of 00 digits compared to other digits. A similar, but weaker, finding is expected around 00 digits in the 1s tests which denotes whole dollar price amounts.

The previous section mentioned research by Bharati, Crain and Kaminski (2012) which offers some similarities to the research in this paper. These researchers test whether there is an interaction

between price clustering and target oil price ranges set by OPEC. They find significant price clustering in NYMEX crude oil futures during time periods when OPEC is attempting to implement target price ranges. Specifically there is clustering around the dollar digit of 9, with the researchers suggesting that this is due to perception of OPEC market intervention around rounded prices ending in 0. However, while evocative and suggestive of psychological barriers, this is not a test of psychological barriers *per se*, but rather a test of whether the market reacts to a reasonable expectation of market intervention at certain price points.

3. Data and Testing Approach

Two NYMEX energy futures are analysed; WTI crude oil and Coal front-month contracts. The coal future is the NYMEX Central Appalachian Coal Future and the oil NYMEX West Texas Intermediate Light Crude Sweet contract. The coal dataset runs from 12th July 2001 to 2nd January 2012 and oil from 10th January 1983 to 2nd January 2012. See Table 1 for descriptive statistics on the two data series. The coal price ranges from $23 to $143 over the time series, while oil ranges from $10 to $145. This price range suggests that the relevant psychological barrier points are in the 10s and 1s digits. As mentioned. 10s means the digits bracketing the decimal point, and the 1s are the two digits to the immediate right of the decimal point. Thus if we examine a series 38.98, 39.02 and 40.05 the 10s digits would be expressed as 89, 90 and 00, and the ones digits 98, 02 and 05.

The main testing approach follows Aggrawal and Lucey (2007) and involves two groups of tests; barrier tests which are akin to price clustering analyses, and tests of conditional effects. Barrier tests consist of proximity and kurtosis (also known as barrier hump) tests. Barrier proximity tests examine whether digits close to a hypothesised psychological barrier show abnormal frequencies and thus act as a test of price clustering without nescessarily investigating the prices around which clustering happens, while Barrier kurtosis tests examine whether there is a significantly different frequency distribution around the numbers being investigated. Tests of conditional effect consider a range of possible different reactions to the particular barrier condition; e.g. whether a price is approaching a barrier point from below or above, and whether the price is approaching a barrier or whether the barrier has been passed.

4. Analysis of Findings

4.1. Primary Barrier Tests

The primary barrier tests suggest some presence of psychological barriers in the pricing of the futures. A barrier is defined as when the price is within 2 of the relevant digit M : thus 98,99,00, 01 and 02 would all be defined as being in a barrier. The defined barrier is turned into a dummy variable, D, taking a value of 1 when digits are in barrier range and 0 otherwise, with the specific equation tested being: $f(M) = \alpha + \beta D + \varepsilon$, where f(M) is the percentage frequency of M-values. The findings from these tests are shown in Table 2. The oil 10s digits are particularly significant, however this is significantly *positive* rather than the expected negative direction (which would show low frequency around barrier points) suggesting the presence of price clustering rather than psychological barriers in oil futures pricing around whole tens of dollars prices, so e.g. when oil is $80, $90,… Similar clustering, rather than barriers, is suggested in coal pricing around whole dollar prices.

The barrier kurtosis (barrier hump) tests examine whether there is a significantly different frequency distribution shape around the barrier points and takes the testing form: $f(M) = \alpha + \varphi M + \gamma M^2 + \varepsilon$, with the M-value being regressed on both itself and the square of itself. If there is no abnormal distribution shape around barrier points then γ should have a coefficient value of 0, while the presence of an abnormal barriers shape would be suggested by a significant negative coefficient, while clustering would be shown in a significant positive coefficient. Table 3 confirms the existence of clustering, rather than psychological barriers in the pricing of oil futures with a significantly positive coefficient.

These initial tests suggest that psychological barriers may not play a role in the pricing of the selected energy futures, but rather price clustering is the dominant feature. This result in itself is interesting given the finding noted in the literature review of psychological barriers in other professionally traded markets (e.g. Aggrawal and Lucey, 2007). The tests also do not exclude the potential presence of conditional psychological barriers in the pricing of these futures.

4.2. Conditional Effects in Psychological Barriers?

A range of conditional effects are tested to determine if there is a differential reaction to the conditions related to the psychological barrier; such as whether the barrier is being approached through rising prices or by prices falling.

Our initial test is an OLS regression with dummy variables based on whether barriers are being approached or after being breached, and also whether a barrier is reached through rising or falling prices. This necessitates setting up four dummy variables with *Down* referring to barriers reached by falling prices, and *Up* referring to barriers reached by rising prices. *Bef* signifies the five days before a barrier is breached and *Aft* signifies the five days after a barrier is breached. Hence the four dummy variables are *Down-Bef*, *Down-Aft*, *Up-Bef*, *Up-Aft*. These dummy variables are tested against returns in order to determine whether the periods covered by each dummy are associated with any anomalous behaviour.

The results from the tests in TABLE 4 show that there appears to be anomalous behaviour in some conditions; particularly when a barrier is approached through falling prices. Specifically both Coal and WTI Oil show significant negative coefficients in the five days after a 10s barrier has been breached from above. Thus, there are significantly negative returns in the days after a psychological barrier has been breached from above. Oil also has significantly negative coefficients in the five day before a barrier is breached.

Psychological barriers might affect variance in addition to returns. TABLE 5 reports three equality-of-variance tests; Levene's test and Brown-Forsythe median and trimmed mean, and finds significant evidence of variance effects in coal, although not in oil. This motivates the GARCH (1,1) tests reported in TABLE 6 which show significant variance effects in a number of the barrier dummies, while largely leaving the mean effects unchanged from that results reported from the OLS regressions in TABLE 4. The general thrust of the findings is of significant negative variance coefficients before a barrier is reached and significant positive coefficients after a barrier is breached. The 1s psychological barriers appear to be more significant than the 10s psychological barriers suggesting that any attention is on whole dollar amounts rather than tens of dollars.

The influence on variance is confirmed in TABLE 7 which reports tests of four conditional hypotheses first proposed by Cyree *et al*. (1999).

H1o: No difference in conditional mean return before and after an upwards crossing of a barrier

H2o: No difference in conditional mean return before and after a downwards crossing of a barrier

H3o: No difference in conditional mean variance before and after an upwards crossing of a barrier

H4o: No difference in conditional mean variance before and after a downwards crossing of a barrier

The results confirm that the main psychological barriers effect are found in the 1s barriers. With the exception of Hypothesis 4 for WTI Oil (which approaches significance at p=0.057) at 1s barriers show significant rejection of all the null hypotheses. Thus there appears to be differences in both returns and variance before and after a whole dollar psychological barrier point. In the 10s barriers only variance appears to show a difference, and interestingly it is the upwards crossing which is highly significant for WTI Oil and the downwards barrier which is highly significant for Coal. The finding for Oil is somewhat supported by Bharati, Crain and Kaminski (2012) which found an OPEC focus on an upper price barrier was responsible for price clustering before the perceived barrier.

5. Conclusions

We confirm previous findings of anomalous price behaviour in energy futures. We expand the battery of tests used to include tests of conditional and unconditional variance and find that there are variance effects.

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TABLES

TABLE 1: DESCRIPTIVE STATISTICS FOR COAL, WTI OIL, AND GASOIL FUTURES

		COAL	WTI OIL
RETURN	*Count*	2732	7560
	Mean	0.0002	0.0002
	Std Dev	0.0166	0.0238
	Skewness	-0.1378	-0.8678
	Kurtosis	9.6684	16.4408
PRICE	*Maximum*	143.25	145.29
	Minimum	23.50	10.42

TABLE 2: BARRIER PROXIMITY TESTS

BARRIER TYPE	CONTRACT	10S DIGITS			1S DIGITS		
		β	*p-value*	R^2	*β*	*p-value*	R^2
REGION:	*WTI Oil*	0.5013	.002	.1161	-0.0473	.862	.0003
M > 98	*Coal*	0.4115	.219	.0154	2.7310	.023	.0517
M < 02							

Barrier proximity test is $f(M) = \alpha + \beta D + \varepsilon$, where f(M) is the percentage frequency of digits for each of WTI Oil, Coal, and Oilgas. Two barrier ranges are set as: *Region 1* where M > 98 or < 02; and *Region 2* where M > 95 or < 05. D is a dummy variable that equals 1 if barrier region and 0 otherwise. 10s digits refers to the two digits in a price bracketing the decimal point, and 1s digits refers to the two digits to the immediate right of the decimal point.

TABLE 3: BARRIER KURTOSIS TESTS

CONTRACT	10S DIGITS			1S DIGITS		
	γ	*p-value*	R^2	*γ*	*p-value*	R^2
WTI OIL	0.0343	.000	.7435	-0.0024	.764	.0011
COAL	0.0033	.735	.0055	0.0192	.587	.0181

Barrier kurtosis test is: $f(M) = \alpha + \varphi M + \gamma M^2 + \varepsilon$, where f(M) is the percentage frequency of digits for each of WTI Oil, Coal, and Oilgas. 10s digits refers to the two digits in a price bracketing the decimal point, and 1s digits refers to the two digits to the immediate right of the decimal point.

TABLE 4: REGRESSION ANALYSIS FOR BARRIERS

VARIABLE	COAL		WTI OIL	
	Coeff	*p-value*	*Coeff*	*p-value*
CONSTANT	0.0004	0.296	0.0006	0.048
UP-BEF	0.0056	0.220	-0.0022	0.175
UP-AFT	0.0010	0.761	0.0004	0.810
DOWN-BEF	-0.0037	0.164	-0.0038	0.041
DOWN-AFT	-0.0143	0.000	-0.0102	0.000
AR(1)	0.1400	0.761	-0.0133	0.543

Results of OLS regression. Up-Bef and *Up-Aft* are dummy variables taking a value of 1 for the five days before (Up-Bef) or after (Up-Aft) approaching a hypothesised 10s psychological barrier from below. *Down-Bef* and *Down-Aft* are similar dummy variables for approaching a barrier from above.

TABLE 5: EQUALITY OF VARIANCE TESTS

TEST	BARRIER	COAL		WTI OIL	
		Test Value	*p-value*	*Test Value*	*p-value*
LEVENE'S TEST (MEAN)	*10s*	3.9362	0.047	1.3049	0.253
	1s	9.4990	0.002	0.1931	0.660
BROWN-FORSYTHE (MEDIAN)	*10s*	2.9910	0.084	1.3667	0.242
	1s	8.5643	0.003	0.3106	0.577
BROWN-FORSYTHE (TRIMMED MEAN)	*10s*	2.6121	0.106	1.4405	0.230
	1s	8.5544	0.003	0.2899	0.590

All three tests take the form:

$$W = \frac{(N-k)}{(k-1)} \frac{\sum_{i=1}^{k} N_i (\overline{Z}_\iota - \bar{Z})^2}{\sum_{i=1}^{k} \sum_{j=1}^{N_i} (Z_{ij} - \overline{Z}_\iota)^2}$$

Where the null hypothesis is that variance is the same across all sub-groups (including sub-groups with prices on days surrounding crossing psychological barrier prices). Significant p-values are a rejection of the null hypothesis.

TABLE 6: GARCH TESTS

VARIABLE	COAL				WTI OIL			
	10s		*1s*		*10s*		*1s*	
	Coeff	*p-value*	*Coeff*	*p-value*	*Coeff*	*p-value*	*Coeff*	*p-value*
CONSTANT	0.000511	0.043	0.000365	0.004	0.000376	0.066	0.000051	0.665
UP-BEF	0.001130	0.691	0.000429	0.674	-0.000112	0.911	-0.000069	0.764
UP-AFT	0.002533	0.414	0.008754	0.000	0.001523	0.301	0.005849	0.001
DOWN-BEF	-0.003847	0.002	-0.057000	0.000	-0.001682	0.166	0.000530	0.794
DOWN-AFT	-0.008771	0.006	0.145000	0.000	-0.004586	0.000	-0.004709	0.001
VARIANCE								
CONSTANT	0.000004	0.000	0.000004	0.000	0.000001	0.182	0.000002	0.000
UP-BEF	-0.000004	0.878	-0.000040	0.000	-0.000024	0.000	-0.000016	0.000
UP-AFT	0.000037	0.183	0.000068	0.000	0.000034	0.009	0.000015	0.000
DOWN-BEF	-0.000052	0.000	-0.007777	0.000	0.000008	0.676	-0.000018	0.000
DOWN-AFT	0.000056	0.004	-0.000687	0.000	-0.000004	0.792	0.000027	0.223

The GARCH equation takes the following form: $R_t = \beta_1 + \beta_2 UpBef + \beta_3 UpAft + \beta_4 DownBef + \beta_5 DownAft + \varepsilon_t . \varepsilon_t \sim N(0, V_t)$; $V_t = \alpha_1 + \alpha_2 UpBef + \alpha_3 UpAft + \alpha_4 DownBef + \alpha_5 DownAft + \alpha_6 V_{t-1} + \alpha_7 \varepsilon_{t-1}^2 + \eta_t$. *UpBef* and *UpAft* are dummy variables taking a value of 1 for the five days before (UpBef) or after (UpAft) approaching a hypothesised psychological barrier from below. *DownBef* and *DownAft* are similar dummy variables for approaching a barrier from above.

TABLE 7: BARRIER HYPOTHESIS TESTS

HYPOTHESIS	BARRIER	COAL		WTI OIL	
		X^2	*p-value*	X^2	*p-value*
H1O: NO DIFFERENCE IN CONDITIONAL MEAN RETURN BEFORE AND AFTER AN UPWARDS CROSSING OF A BARRIER	*10s*	0.1141		0.7616	0.383
	1s	65.9599	0.000	12.1370	0.000
H2O: NO DIFFERENCE IN CONDITIONAL MEAN RETURN BEFORE AND AFTER A DOWNWARDS CROSSING OF A BARRIER	*10s*	2.1333	0.144	3.3272	0.068
	1s	12.9152	0.000	6.4682	0.011
H3O: NO DIFFERENCE IN CONDITIONAL MEAN VARIANCE BEFORE AND AFTER AN UPWARDS CROSSING OF A BARRIER	*10s*	0.6439	0.422	15.6113	0.000
	1s	27.2837	0.000	27.0241	0.000
H4O: NO DIFFERENCE IN CONDITIONAL MEAN VARIANCE BEFORE AND AFTER A DOWNWARDS CROSSING OF A BARRIER	*10s*	31.4794	0.000	0.1267	0.723
	1s	43.2525	0.000	3.6208	0.057

Table shows results for χ^2 tests for the four stated hypotheses.

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